

METHODS AND APPARATUS FOR  
PERFORMING MULTI-VALUE RANGE CHECKS

FIELD OF THE INVENTION

5           The present invention relates generally to microprocessor systems, and more particularly to floating point computations performed within microprocessor systems.

BACKGROUND OF THE INVENTION

10           Most computer systems employ floating point computations in which numbers are represented by a fractional component and an exponential component. The use of floating point computations offers numerous advantages, including the ability to accurately process very large and  
15 very small numbers that generally cannot be processed using a fixed point representation.

          During most floating point computations, a fraction of an addend must be aligned with a fraction of a product before the addend and the product may be added.  
20 Such an alignment is based on the exponent difference of the addend and product.

          For the efficient alignment of an addend and a product, the interval  $F_i$  (as defined by a range  $R_i$ ) in which the exponent difference between the addend and  
25 product lies should be determined. In general, the exponent difference may reside in one of several intervals as defined by ranges  $R_0, R_1, R_2, R_3$ , etc. (e.g., intervals  $F_0=R_0-R_1, F_1=R_1-R_2, F_2=R_2-R_3$ , etc.). Once the particular interval that contains the exponent difference  
30 (e.g., an integer value) is known, the addend and product may be aligned and added or otherwise combined.

One technique for determining in which interval an integer value (such as an exponent difference) resides employs a separate compare circuit for each interval. While effective, the use of a separate compare circuit for each interval is expensive and consumes chip area. A less hardware intensive solution would be desirable.

#### SUMMARY OF THE INVENTION

In a first aspect of the invention, a method is provided for determining in which of  $n$  intervals a sum of two or more numbers resides. The method includes determining the two or more numbers, and providing fewer than  $n$  compress circuits each adapted to (1) input the two or more numbers; (2) input range information regarding ranges used to define the  $n$  intervals; and (3) compress the two or more numbers and the range information into two or more outputs. The method further includes employing the fewer than  $n$  compress circuits to determine in which of the  $n$  intervals the sum of the two or more numbers resides.

In a second aspect of the invention, an apparatus is provided for use in determining in which of  $n$  intervals a sum of two or more numbers resides. The apparatus includes fewer than  $n$  compress circuits each adapted to (1) input the two or more numbers; (2) input range information regarding ranges used to define the  $n$  intervals; and (3) compress the two or more numbers and the range information into two or more outputs. The apparatus further includes a plurality of sign check circuits coupled to the compress circuits, the sign check circuits adapted to generate a sign check bit that corresponds to each of the  $n$  intervals based on the two or more outputs generated by the compress circuits. Numerous other embodiments are

provided in accordance with these and other aspects of the invention.

Other features and aspects of the present invention will become more fully apparent from the following detailed description, the appended claims and the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of conventional range check logic for determining whether an integer resides within an interval  $F_i$  defined by a range  $R_i$ .

FIG. 2 is a block diagram of a conventional four value range check circuit that employs the value range logic of FIG. 1.

FIG. 3 is a block diagram of an inventive four value range check circuit provided in accordance with the present invention.

FIG. 4 is an exemplary schematic diagram that illustrates how propagate and generate logic may be reduced in accordance with the present invention.

#### DETAILED DESCRIPTION

FIG. 1 is a block diagram of conventional range check logic 100 for determining whether an integer resides within an interval  $F_i$  defined by a range  $R_i$ . With reference to FIG. 1, the range check logic 100 includes compress circuitry (e.g., adder logic 102) coupled to sign check logic 104 (collectively referred to as "compare" circuitry or a compare circuit). In the example shown, the sign check logic 104 includes propagate and generate (P,G) logic 106 coupled to carry tree logic 108. The range check

logic 100 and sign check logic 104 may be implemented in hardware, for example, as is known in the art.

The adder logic 102 includes adder circuitry adapted to add a first input A, a second input B and a third input !Ri (e.g., the inverse of the upper limit of the range Ri associated with the logic 100), and to generate a carry vector ci and a sum vector si based on the results of the addition. A 3:2 reduction thereby is produced by the range check logic 102. In the embodiment of FIG. 1, each input A, B and Ri comprises m-bits. In general, any bit size may be employed.

The P,G logic 106 is adapted to perform a bit-by-bit XOR and AND operation on each bit of the sum and carry vectors ci, si so as to generate P and G vectors. The P and G vectors then are fed to the carry tree logic 108.

Based on the P and G vectors produced by the P, G logic 106, the carry tree logic computes the most significant bit (MSB) of the sum of input A, input B and input !Ri (represented as fi in FIG. 1). As is known in the art, the MSB represents the sign of such an addition operation. If the sign of A+B+!Ri is positive (e.g., if the MSB is a logic 0, indicating that A+B-Ri is greater than 0) then the addend A+B does not lie within the interval Fi defined by the range Ri. However, if the sign of A+B+!Ri is negative (e.g., if the MSB is a logic 1, indicating that A+B-Ri is less than or equal to 0) then the addend A+B may lie within the interval Fi defined by the range Ri (as described further below).

FIG. 2 is a block diagram of a conventional four value range check circuit 200 that employs the value range logic 100 of FIG. 1. With reference to FIG. 2, the four value range check circuit 200 includes four single range

check circuits 202a-d each adapted to determine whether an addend A+B lies within one of four intervals F0, F1, F2 and F3 defined by ranges R0, R1, R2 and R3. Each value range check circuit 202a-d may be similar to the single value range logic 100 of FIG. 1.

As shown in FIG. 2, each single range check circuit 202a-d receives inputs A and B. The first single range check circuit 202a also receives input !R0 (e.g., the inverse of the upper limit of the range R0), and the single range check circuits 202b-d receive inputs !R1-!R3, respectively (e.g., the upper limits of ranges R1-R3, respectively). Based on the inputs A, B and a respective range limit value R0-R3, each single range check circuit 202a-d generates a sign check bit f0-f3, respectively. By examining which sign check bits are positive and which sign check bits are negative, the interval F0-F3 in which the addend A+B resides may be found. For example, if sign check bit f0 is positive, and sign check bits f1-f3 are negative, then the addend A+B lies within the interval between the ranges R0 and R1 (e.g., interval F1). Likewise, if sign check bits f0 and f1 are positive, and sign check bits f2 and f3 are negative, then the addend A+B lies within the interval between the ranges R1 and R2 (e.g., interval F2). Table 1 summarizes the interval F0-F3 in which addend A+B resides as indicated by the state of sign check bits f0-f3.

TABLE 1

SIGN BIT f0	SIGN BIT f1	SIGN BIT f2	SIGN BIT f3	INTERVAL
-	-	-	-	0-R0 (F0)
+	-	-	-	R0-R1 (F1)
+	+	-	-	R1-R2 (F2)
+	+	+	-	R2-R3 (F3)
+	+	+	+	>R3

While effective at identifying an interval in which an addend or other integer value resides, the conventional value range check circuit 200 requires a separate compare circuit (e.g., single range check circuit 202a-d) for each interval. As stated, requiring a separate compare circuit for each interval is expensive and consumes device real estate. A less hardware intensive solution would be desirable.

FIG. 3 is a block diagram of an inventive four value range check circuit 300 provided in accordance with the present invention. With reference to FIG. 3, the inventive range check circuit 300 includes first adder logic 302 and second adder logic 304 coupled to first, second, third and fourth sign check logic 306a-d as shown. In the embodiment shown, the first and second adder logic 302, 304 may include, for example, 3:2 add/compress logic adapted to compress 3 inputs into 2 outputs (e.g., a carry vector and a sum vector).

Rather than compressing A+B and !R0, !R1, !R2 and !R3 via separate adder logic, the first adder logic 302 compresses each bit of A+B with 0 and the second adder logic 304 compresses each bit of A+B with 1. For example,

if A and B each comprises n-bits, the first adder logic 302 compresses/adds  $A+B+!0$  (e.g., the inverse of 0) for each bit of A and B. In this manner, a carry vector c0 and a sum vector s0 are generated by the first adder logic 302.

5 Likewise, the second adder logic 304 compresses/adds  $A+B+!1$  (e.g., the inverse of 1) for each bit of A and B. A carry vector c1 and a sum vector s1 thereby are generated by the second adder logic 304.

The carry and sum vectors c0, s0 of the first  
10 adder logic 302 are output to a first bus 308. Similarly, the carry and sum vectors c1, s1 of the second adder logic 304 are output to a second bus 310. As indicated by reference numeral 312a in FIG. 3, the bits of the carry and sum vectors c0, s0 relevant to the range R0 and the first  
15 sign check logic 306a are selectively provided from the first bus 308 to the first sign check logic 306a; and the bits of the carry and sum vectors c1, s1 relevant to the range R0 and the first sign check logic 306a are selectively provided from the second bus 310 to the first  
20 sign check logic 306a. Such bit selection may be achieved, for example, by appropriate wiring between the first and second buses 308, 310 and the first sign check logic 306a. In one embodiment, if the upper limit of the range R0 has n bits (e.g., bits ranging from bit 0 to bit n-1), the bits  
25 of the carry and sum vectors c0, s0 and of the carry and sum vectors c1, s1 may be selectively provided to the first sign check logic 306a as follows:

(1) if a bit j of R0 has a logic value of 0, then  
30 the corresponding bit of carry c0 and the corresponding bit of sum s0 are provided (e.g.,

hard wired) to the first sign check logic 306a;  
and

- 5 (2) if a bit  $j$  of  $R0$  has a logic value of 1, the  
corresponding bit of carry  $c1$  and the  
corresponding bit of sum  $s1$  are provided (e.g.,  
hard wired) to the first sign check logic 306a.

10 Likewise, as indicated by reference numerals 312b-d, the  
bits of the carry and sum vectors  $c0$ ,  $s0$  and  $c1$ ,  $s1$   
relevant to ranges  $R1$ - $R3$  and the sign check logic 306b-d  
may be similarly provided (e.g., hardwired) to sign check  
logic 306b-d.

15 After receiving the appropriate carry and sum  
vectors bits, each sign check logic 306a-b operates  
similarly to the sign check logic of the conventional range  
check logic 200. That is, each sign check logic 306a-b  
generates a sign check bit  $f0$ - $f3$ , respectively, as  
described previously with reference to the conventional  
20 range check logic 200 of FIG. 2. By examining which sign  
check bits are positive and which sign check bits are  
negative, the interval  $F0$ - $F1$  in which the addend  $A+B$   
resides may be found. Table 1 also summarizes the interval  
 $F0$ - $F3$  in which addend  $A+B$  resides as indicated by the state  
25 of sign check bits  $f0$ - $f3$  generated by the inventive value  
range check logic 300 of FIG. 3.

Accordingly, when more than two ranges/intervals  
must be checked, the inventive value range check logic 300  
may identify an interval in which an integer value resides  
30 without requiring separate compress circuits (e.g., adder  
logic) for each interval. In the example shown, two fewer  
compress circuits are required for a four interval system



when the present invention is employed. In general, for  $n$  intervals, the present invention may save  $n-2$  compress circuits.

In accordance with a second aspect of the invention, the complexity of the sign check logic 306a-d also may be reduced. That is, where possible, the propagate and generate (P,G) logic of the sign check logic 306a-d may be shared. For example, if two upper limit range vectors (e.g.,  $R_i$ ,  $R_j$ ) share the same two consecutive bits, the two range vectors may share the P, G logic for one output bit (e.g.,  $f_i$ ,  $f_j$ ). Employing this technique, in the four value range check logic 300 of FIG. 3, the P,G logic for range vector  $R_2$  may be eliminated entirely (as described below).

FIG. 4 is an exemplary schematic diagram that illustrates how propagate and generate logic may be reduced in accordance with the present invention. With reference to FIG. 4, it is assumed that a four value range check is to be performed with intervals that are defined by ranges  $R_0$ - $R_3$  having upper limit vector values of:

	$R_0$	=	1001.1011
	$R_1$	=	1000.0100
	$R_2$	=	1000.0011
25	$R_3$	=	0101.0011

In such an example, range vector  $R_2$  has the same five most significant bits as range vector  $R_1$  (as indicated by reference numeral 402 in FIG. 4). Also, range vector  $R_2$  has the same four least significant bits as range vector  $R_3$  (as indicated by reference numeral 404 in FIG. 4). Accordingly, the sign check logic 306c of FIG. 3 may employ

the P,G logic (not shown) of the sign check logic 306b and of the sign check logic 306d when computing sign check bit f2. A further reduction in range value check logic thereby is realized.

5                   Further reductions in range value check logic may be achieved; and such reductions may be employed with range value check logic having other numbers of ranges/intervals. Table 2 illustrates one exemplary method for determining whether sign check logic may be shared between ranges.

10   With reference to Table 2, bits B0-B7 of the upper limit of range R0 ("range value R0") are aligned with (1) a left shifted version of range value R0; (2) range value R1; and (3) a left shifted version of range value R1. Each column then may be examined to determine if sign check logic may

15   be shared during computation of sign check bit f0 for range R0 and/or of sign check bit f1 for range R1. For example, when the two bits of a column corresponding to a bit of R0 (e.g., R0 and R0 shifted in Table 2) are identical to the corresponding two bits of R1 (e.g., R1 and R1 shifted in

20   Table 2), then sign check logic may be shared during computation of sign check bit f0 and/or sign check bit f1. In Table 2, column B8 reads X,1 for R0, R0 shifted and X,1 for R1, R1 shifted. Accordingly, the same sign check logic may be employed when computing the sign check bits f0 and

25   f1, at least with regard to the most significant bit of R0 and R1. Likewise, because column B7 reads 1,0 for R0, R0 shifted and 1,0 for R1, R1 shifted, and column B6 reads 0,0 for R0, R0 shifted and 0,0 for R1, R1 shifted, the same sign check logic may be employed when computing sign check

30   bits f0 and f1 with regard to the bits B6 and B7 of R0, R1. A similar analysis may be performed for each bit of each range, regardless of the number of ranges employed.

Table 2

	B8	B7	B6	B5	B4	B3	B2	B1	B0
R0	X	1	0	0	1.	1	0	1	1
R0_SHIFTED	1	0	0	1.	1	0	1	1	X
R1	X	1	0	0	0.	0	1	0	0
R1_SHIFTED	1	0	0	0.	0	1	0	0	X

The foregoing description discloses only  
 5 exemplary embodiments of the invention. Modifications of  
 the above disclosed apparatus and method which fall within  
 the scope of the invention will be readily apparent to  
 those of ordinary skill in the art. For instance, while  
 the present invention has been described primarily with  
 10 reference to a four value range check system and method, it  
 will be understood that the invention may be employed for  
 larger or smaller range check applications. Further, the  
 present invention may be employed outside of a floating  
 point context (e.g., in cryptographic engines or in any  
 15 other application that requires multiple ranges to be  
 checked).

In one or more embodiments of the invention, each  
 compress circuit may input and compress more than three  
 inputs. Likewise, each compress circuit may output more  
 20 than two outputs (e.g., rather than just a sum and a  
 carry). The sum  $A+B$  computed by a compress circuit may be,  
 for example, related to an exponent of a floating point  
 addend and an exponent of a floating point product (e.g.,  
 such that the sum  $A+B$  represents a difference between the  
 25 exponent of the addend and the exponent of the product).  
 More generally, the sum  $A+B$  computed by a compress circuit

may be related to an exponent of a first floating point number and an exponent of a second floating point number.

Accordingly, while the present invention has been disclosed in connection with exemplary embodiments thereof,  
5 it should be understood that other embodiments may fall within the spirit and scope of the invention, as defined by the following claims.